

**PROGRAMMABLE CONDUCTOR MEMORY CELL STRUCTURE AND METHOD  
THEREFOR**

Field of the Invention

[0001] This invention relates generally to memory devices for integrated circuits and more particularly to an anode contact for a programmable conductor random access memory (PCRAM) cell.

Background of the Invention

[0002] The digital memory chip most commonly used in computers and computer system components is the dynamic random access memory (DRAM), wherein voltage stored in capacitors represents digital bits of information. Electric power must be supplied to the capacitors to maintain the information because, without frequent refresh cycles, the stored charge dissipates, and the information is lost. Memories that require constant power are known as volatile memories.

[0003] Non-volatile memories do not need frequent refresh cycles to preserve their stored information, so they consume less power than volatile memories. The information stays in the memory even when the power is turned off. There are many applications where non-volatile memories are preferred or required, such as in lap-top and palm-top computers, cell phones or control systems of automobiles. Non-volatile memories include magnetic random access memories (MRAMs), erasable programmable read only memories (EPROMs) and variations thereof.

[0004] Another type of non-volatile memory is the programmable conductor or programmable metallization memory cell, which is described by Kozicki et al. in (U.S. Patent No. 5,761,115; No. 5,914,893; and No. 6,084,796) and is incorporated by reference herein. The programmable conductor cell of Kozicki et al. (also referred to by Kozicki et al. as a "metal dendrite memory") comprises a glass ion conductor, such as a chalcogenide-metal ion glass, and a plurality of electrodes disposed at the surface of the fast ion conductor and spaced a distance apart from one another. The glass/ion element shall be referred to herein as

a "glass electrolyte" or, more generally, "cell body." When a voltage is applied across the anode and cathode, a non-volatile conductive pathway (considered a sidewall "dendrite" by Kozicki et al.) grows from the cathode through or along the cell body towards the anode. The growth of the dendrite depends upon applied voltage and time; the higher the voltage, the faster the growth rate; the longer the time, the longer the dendrite. The dendrite can retract, re-dissolving the metal ions into the cell body, by reversing the polarity of the voltage at the electrodes.

[0005] In the case of a dielectric material, programmable capacitance between electrodes are programmed by the extent of dendrite growth. In the case of resistive material, programmable resistances are also programmed in accordance with the extent of dendrite growth. The resistance or capacitance of the cell thus changes with changing dendrite length. By completely shorting the glass electrolyte, the metal dendrite can cause a radical change in current flow through the cell, defining a different memory state.

[0006] For the proper functioning of a memory device incorporating such a chalcogenide-metal ion glass element, it is important that growth of the conductive pathway have a reproducible relationship to applied voltage. For device operation, multiple cells across an array should ideally have a consistent response to the signals they receive.

[0007] The current invention addresses the issue of consistent memory cell response by ensuring a uniform supply of metal ions for formation of a conductive pathway under applied voltage.

#### Summary of the Invention

[0008] A programmable conductor memory cell for an integrated circuit is disclosed. In accordance with one aspect of the invention, the memory cell includes a memory cell body, formed from a glass electrolyte element having metal ions disposed therein, which fills a cell body via in a first insulating layer. A cathode is in contact with the cell body at the bottom of the cell body via. The second insulating layer, which overlies the first insulating layer and the cell body, has an anode via therein that is positioned concentrically over the memory cell body. The anode via is filled with anode material so that

the anode contacts only a central portion of the anode surface of the memory cell body, which central portion is spaced inwardly from the sidewall of the memory cell body.

[0009] In a preferred embodiment, the anode via is lined with a spacer, preferably of insulating material, to ensure coverage of the sidewall edge of the memory cell body. In another embodiment, the anode via is formed using a mask with an opening smaller in width than the memory cell body and having the opening arranged concentrically over the memory cell body. In this way the sidewall edge of the memory cell body is covered by the second insulating layer.

[0010] The memory cell body can comprise a chalcogenide glass electrolyte material, preferably germanium-selenium, containing metal ions such as silver.

#### Brief Description of the Drawings

[0011] These and other aspects of the invention will be better understood from the description below and the appended drawings, which are meant to illustrate and not to limit the invention, and in which:

[0012] Figure 1a is a cross section of a partially fabricated programmable conductor memory cell for an integrated circuit, constructed in accordance with a preferred embodiment of the present invention.

[0013] Figure 1b is a perspective view of the partially fabricated programmable conductor memory cell of Figure 1a.

[0014] Figure 1c is cross section of a partially fabricated memory cell for and integrated circuit, constructed in accordance with another embodiment of the present invention.

[0015] Figure 2 is a cross section showing an embodiment of the current invention wherein an anode via has a smaller diameter than the memory cell body and is formed concentrically thereover.

[0016] Figure 3 is a cross section showing the programmable conductor memory cell of Figure 1a after deposition of an insulating layer, formation of an anode via therein and deposition of a conformal layer of silicon nitride, according to another embodiment of the current invention.

[0017] Figure 4 is a cross section showing the programmable conductor memory cell of Figure 3 after a spacer etch has been performed.

[0018] Figure 5 is a cross section showing the structure of Figure 3, after a metal layer has been deposited into the spacer-lined anode via.

[0019]

#### Detailed Description of the Preferred Embodiment

[0020] For proper functioning of a "programmable conductor" memory cell device, incorporating a glass electrolyte element with an adjustable conductivity, it is important that the conductive pathway growth in response to a particular applied voltage occurs reproducibly and consistently across an array. Low voltages cause slow growth, whereas higher voltages result in faster growth of the conductive path. The amount of growth in a given switching time depends, in part, on the availability of metal ions. Therefore, it is important that the cations come from a controlled source, such as from the solid solution of the cell body or glass electrolyte, which supplies an amount of cations proportional to the concentration therein and to the electric field. If additional cations are supplied from other, less reliable sources, the amount of cations may not be directly and reproducibly related to the strength of the electric field or switching time.

[0021] For example, the interface between the cell body sidewall and the surrounding insulating layer can provide a diffusion path for metal atoms and ions. When a metal anode layer (e.g., silver) is in contact with the edge (shown in Figure 1b as 115) of the cell body sidewall, i.e., where the sidewall makes contact with the anode surface, there is additional diffusion of metal cations along the sidewall, through the interface, to the growing conductive pathway. If the anode via is designed to have the same width as the cell body via, even slight variations in mask registration can result in large differences in the contact area between the anode and the edge of the cell body sidewall, regardless of conventional mechanisms to minimize the effect of mask misalignment. These differences in contact area lead to differences in the metal supply through the cell body/insulator interface to the growing conductive pathway. Thus, the extent of conductive pathway formation would depend not just on applied voltage and/or switching time, but also on the amount of metal leakage along the sidewall. Accordingly, the preferred embodiments provide means for

avoiding differential contact area between the anode and the edge of the glass electrolyte element.

[0022] A preferred embodiment of the current invention can be described beginning with reference to Figure 1a, wherein the first components of a simplified programmable conductor memory cell for an integrated circuit are shown. A cathode layer 101, which is connected to the negative pole of a power supply, is shown. Preferably, the cathode layer 101 comprises tungsten (W). An insulating layer 103, preferably silicon nitride ( $\text{Si}_3\text{N}_4$ ), is deposited over the cathode layer 101. In other arrangements, it will be understood that the thick planarized insulating layer 103 can comprise a form of silicon oxide, such as TEOS or BPSG, although it is preferred to define the sidewall with a material that prevents the diffusion of metal between devices. The thickness of the insulating layer 103 is preferably between about 10 nm and 200 nm, more preferably between about 25 nm and 100 nm and most preferably about 50 nm. A cell body via 105 is etched through the insulating layer 103, opening a window to the cathode layer 101, using standard patterning and etching techniques. The width of the cell body via 105 is preferably between about 100 nm and 500 nm, more preferably between about 200 nm and 300 nm, and most preferably about 250 nm. The cell body via 105 is filled with a glass electrolyte 107 (sometimes referred to in the literature as a Glass Fast Ion Diffusion or GFID element). The illustrated cell body preferably includes a chalcogenide glass, more preferably a glass comprising germanium and selenium (Ge-Se) and most preferably,  $\text{Ge}_4\text{Se}_6$ ,  $\text{Ge}_3\text{Se}_7$  or  $\text{Ge}_2\text{Se}_8$ , and additionally includes metal ions. The actual ratios of elements in the cell body 107 can vary and more complicated structures for the cell body 107 are also contemplated, one of which is illustrated in Figure 1c and discussed below. Once the cell body via 105 is filled, the top surface 109 of the Ge-Se 107 is made level with the top surface 111 of the insulating layer 103, preferably by chemical mechanical planarization. Preferably the height of the programmable conductor memory cell body between the cathode surface and the anode surface is in the range of about 25 nm to 100 nm.

[0023] Some aspects of the glass electrolyte element that are helpful for understanding the embodiments of the current invention are shown in Figure 1b, a perspective view of the first components of the programmable conductor memory cell

already seen in cross section in Figure 1A. The glass electrolyte element 107 is shown embedded in the insulating layer 103 and making contact with an underlying cathode layer 101. The sidewall 113 of the glass electrolyte element is defined as the outer, cylindrical (in the illustrated embodiment) surface of the element, which is defined by the surrounding via wall 105. The edge 115 of the sidewall 113 is the intersection of the glass electrolyte element sidewall 113 and the top surface 109. In the illustrated embodiment, the edge 115 of the sidewall 113 has the form of a circle.

[0024] In the illustrated embodiment, in order to supply metal ions to the Ge-Se glass, a thin layer (not shown) of metal or a combination of metals, including metal(s) from Group IB or Group IIB, more preferably, silver, copper or zinc, is preferably deposited over a recessed top surface 109 of the fast ion conducting element and metal ions are driven into the glass. The thickness of the metal layer is between about 2 nm and 10 nm, more preferably between about 3 nm and 8 nm and most preferably about 5 nm. For example, silver (Ag) ions can be driven into the Ge-Se material by exposing an overlying Ag layer to ultraviolet radiation with a wavelength less than 50 nm or through plasma treatment. Preferably, there is enough silver available in the layer to form a ternary compound, silver germanium selenide, which is a stable amorphous material. Silver constitutes preferably between about 20% and 50%, more preferably between about 25% and 35% and most preferably about 30% (atomic percent) of the compound. The ternary compound is a glass electrolyte material. The amount of silver formed over the glass is preferably selected to be completely consumed by the photodissolution process. After formation of the glass electrolyte material, the top surface 111 can be planarized again to remove any remaining metal.

[0025] In other arrangements, metal for the programmable conductor memory is supplied by other means. For example, a layer containing a mixture of tungsten-silver of about 50%-50% by weight can be co-sputtered onto the glass electrolyte as a source of silver ions. In still other arrangements, the metal and glass material can be co-sputtered or deposited from a source that contains all species, so no metal deposition and drive-in steps are needed.

[0026] Figure 1c illustrates another arrangement of the cell body 107, wherein like reference numerals are employed to refer to like parts among the different embodiments.

In this arrangement, the cell body 107 includes three layers, comprising a first Ge-Se layer 107a (e.g.,  $\text{Ge}_4\text{Se}_6$ ), a metal selenide layer 107b (e.g.,  $\text{Ag}_2\text{Se}$ ) and a second Ge-Se layer 107c (e.g.,  $\text{Ge}_4\text{Se}_6$ ). The skilled artisan will appreciate that the embodiments discussed below are equally applicable to forming electrodes over the cell body 107 of Figure 1a, Figure 1b or of any of a variety of other programmable conductor arrangements. In the illustrated embodiment of Figure 1c, the intermediate layer 107b provides metal to the cell body 107 for formation of conductive pathways under the influence of applied electrical fields. The structure can be formed by blanket deposition and etch or by first forming and then filling a via. In either case, the sidewall of the insulator surrounding the cell body is referred to as a "via" herein.

[0027] Regardless of how formed, the cell body or glass electrolyte element 107, including metal ions diffused therein, serves as the memory cell body.

[0028] With reference to Figure 2, a second insulating layer 121, preferably silicon nitride, is deposited over the first insulating layer 103. The thickness of the second insulating layer 121 is preferably between about 50 nm and 200 nm, more preferably between about 80 nm and 150 nm and most preferably about 100 nm. An anode via 123 is etched through the  $\text{Si}_3\text{N}_4$  directly over the cell body via, exposing the glass electrolyte element 107.

[0029] In some arrangements, metal deposition and drive-in steps can be performed after etching the anode via instead of before deposition of the second insulating layer 121 as described above.

[0030] In the embodiment of Figure 2, the width of the anode via 123 in insulating layer 121 is smaller than the width of the cell body 107 in insulating layer 103, preferably by between about 10 nm and 100 nm and more preferably by between about 10 nm and 60 nm. The anode via 123 is positioned over the cell body 107 roughly concentrically, that is, so that the sidewall of anode via 123 is spaced from the sidewall of cell body 107 all the way around, and only a central portion of the cell body 107 is exposed.

[0031] Referring now to Figure 3, the anode via 123 and the cell body via 105 have about the same size and are aligned directly over one another, in accordance with another embodiment of the invention. Methods known in the art can be used to avoid mask misalignment problems. Additionally, a thin blanket layer 125 of spacer material, preferably

an insulating material and most preferably  $\text{Si}_3\text{N}_4$ , is deposited conformally over the insulating layer 121 and the anode via 123. The skilled artisan will appreciate, in view of the disclosure herein, that the spacer material need not be the same as the surrounding insulating layer, although it is preferably a barrier to metal diffusion, particularly to diffusion of the fast diffusing element incorporated into the cell body 107 and anode to be formed. The thickness of the spacer layer 125 is preferably between about 5 nm and 50 nm and more preferably between about 5 nm and 30 nm.

[0032] Referring to Figure 4, a spacer etch is performed, preferably by reactive ion etching (RIE), wherein horizontal portions 127 (Figure 3) of the spacer layer 125 are removed preferentially, leaving vertical portions of the spacer layer 125 relatively unaffected. Figure 4 shows the vertical portions of the spacer layer 125 that remain after RIE, leaving a the spacer 131 lining vertical surfaces of the anode via 123. It will be understood that the spacer 131 forms a continuous lining around the sidewall of the anode via 123. In the illustrated embodiment, the spacer 131 is a cylindrical annulus with a rounded top edge, whose outer side surface is in contact with the sidewall of the anode via 123.

[0033] Next, as shown in Figure 5, a metal anode layer 133, preferably including a metal or combination of metals from Group IB or Group IIB, more preferably copper or zinc and most preferably silver, is deposited. Preferably, the metal anode layer 133 is deposited so that it fills the anode via 123 and forms a portion 135 overlying the second insulating layer 121 all as one contiguous body of material. The overlying portion 135 is subsequently patterned and etched as desired, depending upon the circuit design of the memory array.

[0034] In Figure 5, the metal deposition is shown for an anode via 123 with a spacer 131. The anode via filling and overlying anode layer can be deposited in this same manner for the embodiment described with respect to Figure 2, having an anode via 123 that is narrow (compared to the cell body 107) without a spacer. In both the embodiment of Figure 2 and the embodiment of Figure 4, the anode makes contact with only a central portion of the memory cell body and not with the sidewall edges.

[0035] When a voltage is applied across the lower electrode 101 and upper electrode 133, a conductive path forms between the cathode 101 (i.e., the electrode connected



to the negative pole of the power supply) and the anode 133 (i.e., the electrode connected to the positive pole of the power supply). Without being limited by theory, it is believed that the conductive path grows by precipitation of cations (e.g., silver cations) from the memory cell body 107. Changes in the extent of the conductive path affect the overall resistance of the device. The conductive path tends to remain intact when the voltage is removed.

[0036] For a binary programmable conductor memory device, the memory has two basic states: 0 and 1. When there is no conductive path, the memory cell has high electrical resistance and reads as 0. When the conductive path shorts the memory cell body 107, from the cathode 101 to the anode 133, the resistance is low and the memory cell reads as 1. The change in resistance of the memory cell with and without a conductive path can be as much as two orders of magnitude, e.g., a change from Megaohms to milliohms. Reversing the polarity of the voltage reverses the formation of the conductive path, redissolving metal cations into the glass.

[0037] Alternatively, the memory cell can be programmed into as many as 3 or 4 states by setting the extent of the conductive path growth. These changes can be detected easily by the bit lines and word lines in a memory array, such that changing the extent of the conductive path can serve to change the state of the memory bit.

[0038] Thus, in one embodiment of the current invention, an anode via is made smaller than the cell body via so that the overlying insulator layer covers the cell body/insulator interface. The smaller anode vias are positioned so that their bottoms make contact only with the cell body and do not extend to the cell body/insulator interface. In another embodiment, a spacer prevents contact between the anode material and the cell body/insulator interface by covering the interface with spacer material near the outer edge of the anode via bottom. The preferred embodiments thus give reliable control to the spacing between the edge of the anode and the edge of the memory cell body or GFID material. These structures ensure that the anode cations that precipitate out to form the conductive path are those that were intentionally and controllably provide to the glass electrolyte material, whether by photodissolution, separate metal-containing layer (see Figure 1c), co-deposition or any other manner of metal doping. Silver content dissolved within a GeSe glass, for example, is self limiting at about 30 atm %, thus providing a reliably consistent source of

diffusion ions for selectively forming the conductive path. For a given cation (e.g., Ag) concentration in solution, this provides conductive pathway formation reproducibly dependent upon voltage applied across the electrodes and/or switching time.

[0039] Although the embodiments of the invention have been described in the context of a vertically built device, one of skill in the art will recognize that this is not the only possible configuration or method for constructing a programmable conductor memory cell.